IMAGING ASSEMBLY

[001] This is a Continuation-In-Part Application from earlier application docket SNX 0304 having Serial Number 10/620,676 filed 07/17/03 and having a common inventor

[002] FIELD OF THE INVENTION

[003] This invention relates to compact lenses for digital camera applications and, in particular, to lenses for very compact digital cameras such as could be incorporated into a cellular telephone, personal digital assistant, or other very small electronic device.

[004] BACKGROUND OF THE INVENTION

[005] Digital cameras utilizing high-resolution electronic imaging sensors require high resolution optics. For the consumer market, it is important that such lenses be produced in high volume and inexpensively. For use in very compact digital cameras, and cameras that might be incorporated into devices such as palm-sized computers, cellular telephones and the like, the lens must be very compact. In particular, lenses for such applications must have a very short length or height when measured from the lens front surface to the image plane. Micro-lens arrays are used on modern CCD/CMOS imagers to enhance their low light performance. A technical drawback of micro-lens array is that they limit the "field of view" to the pixels behind them. Therefore, the primary imaging lenses must be designed to be compatible with the micro-lens arrays. This requires that the off-axis rays exiting the image lens strike the imager image plane at near normal incidence. A lens meeting this normal incidence requirement is known as a "telecentric" lens.

[006] It is extremely difficult to design and manufacture a lens which is both short (relative to its image circle) and telecentric. Many well-known classical lens design forms such as Cooke triplet, Double Gaussian lens, etc., fall short of meeting both of these requirements.

[007] Aspherical lenses have some optical advantages, but cannot be easily produced by traditional glass grinding and polishing techniques. Aspheric elements are typically produced by molding plastics or low melt temperature glasses. While molded plastic elements are inexpensive to produce, the level of precision of the lenses is not always sufficient for high-resolution cameras, especially if a plastic element is used primarily as a focusing element. In addition, the optical properties of most plastic materials change with changes in temperature and humidity. The index of refraction of the plastic lens materials changes with changes in temperature, such as going in and out of doors on very hot or very cold days. This change is a significant problem with the focusing element(s), but is of much less consequence with other elements which primarily correct for aberrations. Lenses with all glass elements can overcome this problem, but tend to be large and excessively expensive for use in compact digital cameras used in other devices, such as an accessory built into a cellular phone.

[008] In US Patent 6,441,971, the present applicant and inventor describes a three-element objective lens. The final lens element is shown as an aspheric plastic element. However this design has limited image quality which makes it unsuitable for high-resolution imagers with pixel counts greater than 1 million known as megapixel imagers. A separate infrared cut-off (IR) filter is also required. This makes this design more expensive to manufacture.

[009] Therefore, there is a continuing need for improved lenses that have excellent optical performance and are compact, short, light weight and inexpensive to produce while using conventional, well-proven manufacturing methods.

SUMMARY OF THE INVENTION

[0010] The above-noted problems, and others, are overcome in accordance with this invention by a lens for digital cameras; in particular, such cameras that are incorporated into another device such as a cell phone, personal digital assistant and the like, that is extremely compact and has a short length from the front element surface to the imaging plane, have three lens elements having excellent optical characteristics.

[0011] The objective lens of the present invention comprises three optical elements with each element serving a distinct optical function. The first optical element is a lens group and it can consist of from one lens element to three lens elements. The lens group has a positive optical power. In a first embodiment, the lens group is a singlet and has a single lens element. In a second embodiment, the lens group is a doublet and has two lens elements. In a third embodiment, the lens group is a triplet and has three lens elements. A middle lens element follows the lens group and is a single lens element with a meniscus shape (i.e., one side is concave and the other is convex) with the concave side facing the lens group. This group will be identified as the middle lens element. The third lens group is also a single element with a positive power. This group will be identified as the final lens element. The final lens element can be either bi-convex or plano-convex. The primary function of the third element is to reduce the angle of incidence of off-axis rays to the image plane. The primary function of the middle lens element 36 is to reduce the off-axis optical aberrations of the lens group 34 and that of the final lens element 38 allowing the complete imaging assembly to achieve high image quality. The surface profiles of all of the lens element can be aspherical to gain further performance (i.e. surfaces that are not spherical but described by a general mathematical equation). An electronic imaging sensor 14 is spaced at a suitable distance from the final lens element.

[0012] In the preferred embodiment, an IR cut-off coating is also applied to the image surface of the final lens element to produce an integrated imaging lens with IR cut-off

function. This eliminates the need for a separate IR cut-off filter in addition to the lens, thus making the entire optical assembly less costly to manufacture.

[0013] In the preferred embodiment, the lens group elements are all made of glass. The use of glass material for the lens elements reduces the sensitivity of the lens to dramatic temperature changes. A reduced temperature sensitivity provides for stabilized performance such as when a camera using the objective lens is moved from an exterior location into an interior where a substantial temperature difference exists between the two locations.

[0014] It is, therefore, an object of this invention to provide an imaging assembly particularly suitable for use in high resolution compact digital cameras with megapixel imagers, especially those incorporated into other compact electronic devices such as cellular phones, personal digital assistants and the like.

[0015] Another object of this invention is to provide an imaging assembly for digital cameras that has very low sensitivity to changes in temperature.

[0016] A further object is to provide a digital camera lens having an extremely short length from the front surface of the lens to the image plane, and having a reduced angle of incidence for the off-axis rays on the image plane.

[0017] Yet another object is to provide a digital camera lens having an integrated IR cut-off coating to provide an optimum combination of imaging quality, small F-stop, and low manufacturing cost.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Details of the invention, and of preferred embodiments, will be further understood upon reference to the drawing, wherein:

[0019] FIG. 1 is a schematic side view showing, in sequence, a lens group, a middle lens element and a final lens element aligned on the optical axis from left to right with an object on the left and an electronic imager at the right, the lens group being represented by a phantom block having an object and an image surface;

[0020] FIG. 2a is a schematic side view of a first embodiment of the lens group within the phantom box in Figure 1, the first embodiment of the lens group being a singlet lens element;

[0021] FIG. 2b is a schematic side view of a second embodiment of the lens group within the phantom box in Figure 1, the second embodiment of the lens group being a doublet lens group; and

[0022] FIG. 2c is a schematic side view of a third embodiment of the lens group within the phantom box in Figure 1, the third embodiment of the lens group being a Cook triplet lens group.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0023] Figure 1 shows the imaging assembly 10. The imaging assembly 10 comprises an objective lens 12 and an electronic imager 14. The objective lens12 has three optical elements that include a lens group 34, a middle lens 36 and a final lens 38. The three optical elements and the electronic imager 14 are coupled together and held in optical alignment on the optical axis from left to right by a frame represented by phantom line 22. The combination of the objective lens 12 and the electronic imager 14 on frame 22 is received by a camera body represented by phantom line 24.

[0024] The electronic imager 14 has an image plane 26 formed on an active surface .The image plane 26 is typically rectangular in shape with a maximum effective dimension DI measured as the diagonal distance across the rectangular image plane 26.

[0025] The objective lens 12 receives light rays from an object 30 in object space at the left and processes the light rays to form an image of the object (not shown) on the image plane 26. The objective lens 12 has three optical elements which include a lens group represented by block 34, a middle lens element 36 and a final lens element 38. The lens group 34 has an object surface 40 facing the object 30 and an image surface 42. The middle lens element 36 has a object surface 44 facing the lens group image surface 42 and an image surface 46. The final lens element 38 has a object surface 48 facing the middle lens element image surface 46 and an image surface 50 facing the image plane 26. The frame 22 holds each of the three lens elements and the electronic imager 14 in optical alignment on the optical axis 54. The image plane 26 is normal to the optical axis 54.

[0026] The electronic imager 14 is a purchased CCD or CMOS imager such as the Sony ICX098 CCD imager. Operation of the electronic imager 14 is supported by the control and processing electronics 56. Signal leads 58 schematically represent the cabling necessary to carry image signals, control levels and power from the electronic imager 14 to the camera electronics and processor 56.

[0027] The image plane 26 on the electronic imager 14 is typically a window or active surface that may be covered by a glass or other transparent cover (not shown) to reduce the sensitivity of the electronic imager 14 to environmental effects. Bracket 62 schematically represents the maximum diameter of an image formed on the image plane 26.

[0028] The objective lens 12 has a focal length f0. Figures 2a, 2b and 2c show alternative embodiments for the lens group 34. Fig. 2a shows a first embodiment comprising a singlet lens. Fig. 2b depicts a second embodiment of the lens group 34 as a doublet lens arrangement. Fig. 2c shows a third embodiment of the lens group as a triplet lens arrangement. Lens group 34 is the main focus group of the imaging assembly 10.

[0029] The lens group 34 in each of its three alternative embodiments has a focal length f1 that is greater than zero ($f1 > 0$). The design forms for the lens group 34 embodiments include a positively powered meniscus singlet shown in Figure 2a, a cemented doublet shown in Figure 2b and the three-element Cooke triple such as that shown in Figure 2c.

[0030] The lens group 34 is designed to obtain the ratio of f1/f0 in the range of: 0.5 to 2.0. . The result of positioning the ratio of f1/f0 to be in the stated range provides that most of the focusing power for the objective lens 12 is satisfied by the lens group 34. The middle and final lens elements 36 and 38 provide aberration compensation to correct optical aberrations present in the lens group 34. The middle and final lens elements 36 and 38 also direct and focus rays passing through the center of the aperture stop to strike the image plane 26 at a reduced angle of incidence.

[0031] The lens elements in lens group 34 are made from either plastic or glass depending on the application. Plastic elements in general allow for a lower manufacturing cost; however, glass elements are preferred if the operational

requirements for the imaging assembly 10 require that the imaging assembly 10 have a high level of thermal stability. In an embodiment that requires high thermal stability, all of the elements in the lens group34 are made from a glass material selected for its high thermal stability.

[0032] An imaging assembly 10 designed for high thermal stability avoids any problems resulting from moving the lens between operational areas that have greatly differing temperatures. A typical design might require that the optical performance of the imaging assembly 10 remain substantially unchanged or that it be maintained with an imperceptible level of degradation as the imaging assembly 10 is transferred from an outdoor environment on a very hot or a very cold day to an indoor environment.

[0033] Figure 1 shows that the middle lens element 36 in the present invention has a meniscus shape. The object surface 44 is concave and the image surface 46 is convex. The object surface 44 of this element faces the image surface 42 of the lens group 34. The optical function of the middle lens element 36 is to direct light rays exiting from the lens group image surface 42 and more particularly to provide off-axis optical aberration corrections to light rays passing from the lens group image surface 42 to the object surface 48 of the final lens element 38.

[0034] The final lens element 38 has positive optical power. The positive optical power of the final lens element 38 permits it to reduce the angle of incidence of off-axis rays as they reach the image plane 26. The use of a micro-lens array also reduces the "acceptance" angle of each pixel on an image plane such as image plane 26. In order to achieve the optimal image quality, off-axis light rays exiting the lens group 34 must strike the image plane 26 with near normal incidence. The primary function of the final lens element 38 in the imaging assembly 10 is to satisfy this requirement. The final lens element 38 is made of glass or plastic material depending on the requirement for thermal stability. If plastic material or moldable glass material is used, it is preferable to

use aspheric profiles on both or one of the surfaces to gain additional aberration correction capabilities of the aspheric surfaces.

[0035] The positive power requirement for the final lens element 38 mandates that the lens shape be selected from a family of shapes that include a bi-convex, a plano-convex or positive meniscus shape. An embodiment of the final lens element 38 that elects to use a plano-convex shaped element with the plano-side (the image surface 50) facing the image plane 26 is of particular interest because it allows the IR coating to be deposited with improved uniformly across the lens surface.

[0036] Electronic imagers today have significant spectral response above the visible range of 400-700nm. For digital camera applications, tests have shown best performance is obtained by limiting the spectral band-pass of the optics to a range that extends from 400nm to about 700nm. The spectral band is limited by the use of an interference coating referred to as an IR cut-off coating. The IR cut-off coating is typically formed on the surface of a lens with multiple layers of optical material, each layer having its own specific index of refraction and its own thickness. The filter is structured to transmit light within its spectral band and to reflect light outside the spectral band. The design theory and practice of IR coatings of this type is well understood in the art and is available in texts such as "Thin-Film Optical Filters" by H. A. Macleod. The third edition of the text with 672 pages was published in June 2000 by the Institute of Physics Publishing and is identified by its ISBN: 0750306882.

[0037] Applying the coating directly to the image surface 50 provides a more compact lens design and reduces the cost of the whole product by the elimination of a separate component, such as a coated plate. A cost saving advantage of the present invention is that the IR coating can be directly applied to the substantially flat final lens element image surface 50. The material of the final lens element 38 and the substantially flat shape of the final lens element image surface 50 is compatible with the IR cut-off filter coating process. If the surface to be coated is not substantially flat, an applied coating tends to not be uniform in thickness. The result is that the filter properties of regions

across the surface of the coated lens surface are not uniform. In addition, the use of glass as a material for the final lens element 38 eliminates the possibility of image distortion that is encountered when high temperatures are used to apply coatings to plastic lenses. If the material to be used is plastic, and if the temperature is high enough, the lens can deform or warp or even melt during the coating process.

[0038] If the middle lens element 36 and or the final lens element 38 are to have an aspherical surface, and if cost is to be reduced, the lens group 34, the middle lens element 36 and the final lens element 38 respectively, should be made from plastic using a manufacturing technique that is suitable for producing aspheric surfaces . If the material selected for these lens elements is plastic, precision molding is used to insure precision and product quality. If glass is to be used, a glass molding process is used to make the lens elements. As explained above, the middle lens element 36 and the final lens element 38 provide most of the aberration correction of the objective. It is therefore reasonable to believe that the use of plastic material for the middle lens element 36 and the final lens element 38 will have a minimal influence on the focus stability of the imaging assembly 10 even though the plastic material to be used would be more sensitive to temperature and other environmental conditions than glass.

[0039] Referring to Figure 1, objective lens 12 has a height TT shown as dimension 60. The height or length of the objective TT is shown to be equal to the sum of the thickness of the lens group 34, the middle lens element 36 and final lens element 38 plus the distance between the lens elements and the distance to the image plane. the height is therefore the sum of the distances characterized as dimensions 66, 68, and 70 plus the separation distances 88, 90 and 92. Each of the respective lens thicknesses are measured as the distance between the first and second vertex of each respective lens. The three thicknesses are then added to the separation distance 88 between the lens group second vertex 80 and the middle lens element first vertex 76. The resulting sum is then added to separation distance 90; the distance between the middle lens element second vertex 82 and the final lens element first vertex 78. The resulting sum is then

added to the image plane distance 92, the separation between the final lens element second vertex 78 and center of the image plane 94.

[0040] The frame 22 aligns and couples the objective lens 12 with the electronic imager 14 to form the imaging assembly 10. The imaging assembly 10 is then connected to the camera electronics and processor 56 via signal leads 58. The imaging assembly 10 is then assembled into the camera body 24 for use in a digital camera (not shown).

[0041] The height TT (dimension 60) of the imaging assembly 10 of the present invention is very short relative to the size of the image, DI, that it provides. An electronic camera using an objective lens such as the imaging assembly 10 forms an image represented by bracket 62 on the image plane 26 on the electronic imager 14. Bracket 62 on the image plane 26 schematically identifies the limits of the image formed on the image plane. The effective imaging area of the electronic imager 14 is typically rectangular in shape with a diagonal size equal to dimension DI. The objective lens 12 forms a circular image on the image plane 26 with a diameter equal or greater than DI to provide a complete rectangular image and to achieve acceptable image quality.

[0042] As explained above, the lens height or total track (TT) is shown as dimension 60 along frame 22 at the base of Figure 1. The height or total track is defined as the distance from the lens group object surface vertex 74 to the image plane 26. The COMPACTNESS of the optical imager 10 is defined by the ratio of TT to DI. As this ratio is reduced, the resulting lens is shorter and more appealing for use in hand held appliances. For prior art lens designs, this ratio is believed to be greater than 1.3. However, the objective lens 12 of the present invention obtains an improvement in this ratio such that the ratio of $TT/DI<1.3$. With the ratio of $TT/DI < 1.3$, the optical imager assembly 44, which includes the imaging assembly 10, is considered to be a low profile optical imager which makes it suitable for compact digital camera modules such as those used in cell phones. The use of the imaging assembly 10 of the present invention of Figures 1 and Figures 2a through Figure 2c in combination with a suitable selection

of optical material and by forming the elements to comply with the prescriptions of Tables 1 through 5 achieves an imaging assembly 10 with excellent image quality and with a ratio of TT/DI < 1.3.

[0043] A first preferred embodiment of the present invention is obtained using the prescriptions of Table 1 and Table 2. The singlet lens 96 of Figure 2a is characterized in rows 1, 2 and 3 of Table 1. The singlet lens 96 within phantom block 34a of Figure 2a is substituted for the lens group 34 in Figure 1. The object surface 40a collects rays of light from the object 30. Table 1, row 2 shows that the radius of surface 40a is 1.64 mm and the thickness, represented by dimension 66 on Figure 1 between vertex 76 and vertex 80 in Figure 2a, at the lens center is 1.49 mm . Table 1, Row 3 shows that the second surface of singlet lens 96 has a radius of 3.29 mm. The distance to the vertex 76 on the object surface of the middle lens element 36 is 0.64 mm. The stop or aperture stop is formed on the image surface of the singlet lens 96. Row 2 of Table 1 shows that the material for singlet 96 has a refractive index of 1.618 at d-line at 587nm. The Abbe number of the material is 63.4. Rows 1, 2 and 3 show that the type of lens is STANDARD. That term shows that the surfaces 40a and 42a are spherical. Row three shows that the distance from the second vertex 80 to the first vertex of the middle lens element, dimension 88, is 0.64 mm.

Table 1						
Surface	SURFACE DATA SUMMARY (Singlet 34a)					
	Surface Number	Type	Radius	Thickness	Nd	Abbe
1	OBJECT,30	STANDARD	Infinity	Infinity		
2	40a	STANDARD	1.64	1.49	1.618	63.4
3	a (STO)	STANDARD	3.29	0.64		
4	44	EVENASPH	-2.28	1.34	1.689	31.2
5	46	EVENASPH	-5.68	0.10		
6	48	STANDARD	5.88	1.22	1.801	44.3
7	50	STANDARD	8582.37	1.21		
8		STANDARD	Infinity			

[0044] Row 4 of Table 1 characterizes the properties of the middle lens element object surface 44 and Row 5 of Table 1 characterizes image surface 46 of the middle lens element 36. Rows 4 and 5 designate both lens surfaces as EVENASPH or even aspheric.

[0045] Row 4 of Table 1 shows that the radius of object surface 44 is -2.28 mm. The thickness or dimension 68 of the middle lens element 36 between vertex 76 and 82 is 1.34 mm. The material for the middle lens 36 has a refractive index of 1.689 at d-line at 587 nm. The Abbe number of the material is 31.2. The coefficients for the surface radius and height "z" definition are presented in Table 2.

[0046] Row 5 of Table 1 shows that the image surface 46 has a radius of -5.68 mm. The thickness column shows that the distance from the middle lens element vertex 82 to the final lens element object surface vertex 78, dimension 90, is 0.1 mm.

[0047] Rows 6 and 7 of Table 1 provide the prescription for the final lens element 38 in Figure 1. Row 6 shows that the radius of the final lens element object surface 48 is 5.88 mm and the thickness or dimension 70 from the vertex 78 to vertex 84 is 1.22 mm. The material for the final lens 38 has a refractive index of 1.801 at d-line at 587nm. The Abbe number of the material is 44.3.

[0048] Row 7 shows that the image surface 50 of the final lens 38 has a radius of 8582.37 mm. A large radius approximates a substantially flat surface. The distance 92 from the vertex 84 to the image plane 26 is 1.21 mm.

[0049] The term "STANDARD" is used to indicate a spherical surface, and "EVENASPH " is used herein to indicate an "aspheric" type surface characterized by an even ordered polynomial such as Equation 1 below. Such terms are conventional in the field of lens design. The terms "STANDARD" and EVENASPH as used in this specification and in the claims are to be interpreted in accordance with their conventional meanings and in support of a lens surface equation such as Equation 1 below. The legend EVENSPH that appears in Tables 1 with a column heading "TYPE" requires that the surface be first formed in accordance with the requirements of the surface description of Table 1 and then further characterized by an even ordered polynomial such as Equation 1. The legend STANDARD implies that the surface is spherical in character and is not followed by an aspherical surface correction.

[0050] Equation 1 provides the sag or surface displacement "z" measured from a plane passing through a surface vertex of the lens, the plane being normal to the optical axis.

$$\text{Eq. 1} \quad z = \frac{c\,y^2}{1+\left[1-(1+k)c^2y^2\right]^{1/2}} + Dy^4 + Ey^6 + Fy^8 + Gy^{10} + Hy^{12} + Iy^{14}$$

[0051] The distance "z" is measured at a distance or radius "y" from the optical axis 54 of the imaging assembly 10. The coefficient "c" is the curvature of the lens at the optical axis and it is equal to the reciprocal of the radius. The coefficient "k" is a conic constant. A surface is spherical if "k" and "D" through "I" are all zero. A surface is an aspherical surface if either "k" or any of the coefficients "D" through "I" are non-zero.

[0052] Table 2 has a first and second set of six rows each. The first or top set provides the D, E, F and G coefficients for a prescription in accordance with Equation 1 for the middle lens element object surface 44. The second or lower set provides the D, E, F and G coefficients for a prescription in accordance with Equation 1 for the middle lens element image surface 46.

Table 2		
Aspheric coefficients for surfaces of the middle lens element 36		
Row	Surface 44 of the middle lens element 36 Evenasph Lens	
1	D	-0.079282116
2	E	-0.19307826
3	F	0.48564859
4	G	-0.71896107
5	H	0
6	I	0
	Surface 46 of the middle lens element 36 Evenasph Lens	
1	D	-0.002466236
2	E	-0.010260173
3	F	0.002754689
4	G	-0.000681387
5	H	0
6	I	0

[0053] <u>DOUBLET COMBINATION</u>

[0054] A second preferred embodiment of the present invention is obtained using the prescriptions of Table 3 and Table 4. The doublet lens within phantom box 34b in Figure 2b is substituted for the lens group 34 in Figure 1 and a prescription for its surfaces is provided in rows 1, 2, 3 and 4 of Table 3. As in the case of the first embodiment, the lens group object surface (40b) collects rays of light from the object 30. Figure 2b shows the doublet formed from first lens elements 98 and second lens element 100. The three lens surfaces are characterized as STANDARD, therefore, each of the three surfaces are spherical surfaces.

[0055] Row 2 of Table 3 shows that the radius of surface 40b is 1.715843 mm and the thickness of lens element 98 is 1.423295 mm. The index and abber number of the material is shown in the table.

[0056] Row 3 of Table 3 shows that the radius of surface 41a is -3.767583. The thickness of lens element 100 is 0.32525 mm. The index and abber number of the material is shown in the table.

[0057] Row 4 of Table 3 shows that the radius of surface 42b is 3.227809 mm. The dimension distance between vertex 80 the stop is 0.54069 mm

[0058] Row 5 provides a prescription for the middle lens element object surface 44. The radius is -2.8859 mm so the lens is concave. The thickness is 1.217885 mm The index and abber number of the material is shown in the table.

[0059] Row 6 provides a prescription for the middle lens element image surface 46. The radius is 7.761245 mm so the lens is convex. The distance 90 is measured between the vertex 82 and 78 and is equal to 0.1 mm.

[0060] Row 8 provides the radius of the final lens element image surface 40 as -7.818260 mm and the distance to the image plane 26 as being 0.999993 mm. Row 9 shows that the image plane has a spherical surface with an infinite radius which is the characterization for a flat surface.

Table 3						
SURFACE DATA SUMMARY (doublet 34b)						
Row	Surface	Type	Radius	Thickness	Index	Abbe
1	OBJ 30	STANDARD	Infinity	Infinity		
2	40b	STANDARD	1.715843	1.423295	1.641	60.1
3	41a	STANDARD	-3.767582	0.325250	1.673	32.2
4	42b & STOP	STANDARD	3.227809	0.540690		
5	34	EVENASPH	-2.885900	1.217885	1.491	57.4
6	36	EVENASPH	7.761245	0.100000		
7	38	STANDARD	7.818255	1.392907	1.855	36.6
8	40	STANDARD	-7.818260	0.999993		
9	IMA	STANDARD	Infinity			

[0062] Table 4 has a first and second set of six rows each. Table 4 is used in connection with Table 3 to characterize the middle lens element surfaces 44 and 46 for the second embodiment using the doublet of Figure 2b. The first or top set provides the D, E, F and G coefficients for a prescription in accordance with Equation 1 for middle lens element object surface 44. The second or lower set provides the D, E, F and G coefficients for a prescription in accordance with Equation 1 for the middle lens element image surface 46. Coefficients are not provided by rows 5 and 6 for coefficients H and I. These coefficients would be initialized to be zero.

Table 4		
Aspheric coefficients for surfaces of the middle lens element 36		
Row	Surface 44 of the middle lens element 36 Evenasph Lens	
1	D	-0.15545497
2	E	-0.1693017
3	F	0.58931065
4	G	-1.0012036
5	H	
6	I	
	Surface 46 of the middle lens element 36 Evenasph Lens	
1	D	-0.026801269
2	E	0.000946834
3	F	-0.000221566
4	G	-7.01E-05
5	H	
6	I	

TRIPLET COMBINATION

[0064] Table 5 provides a third preferred embodiment of the present invention. The surfaces all being STANDARD there are no aspheric surfaces. The triplet lens within phantom box 34c in Figure 2c is substituted for the lens group 34 in Figure 1 and a prescription for its surfaces is provided in rows 1, 2, 3, 4, 5, 6 and 7 of Table 3. As in the case of the first embodiment, the lens group object surface (40c) collects rays of light from the object 30. Figure 2c shows the triplet formed from first lens elements 10, second lens element 104 and third lens element 106. The three lens surfaces are characterized as STANDARD, therefore, each of the three surfaces are spherical surfaces.

[0065] Row 2 of Table 5 shows that the radius of surface 40c is 2.25801 mm and the thickness of lens element 102 is 1.058656 mm.

[0066] Row 3 of Table 5 shows that the radius of surface 41b is 7.551701. The distance to the vertex on object surface 41c of lens element 104 is 0.1086743 mm and the index of refraction is 1.673048. A stop is positioned between surface 41b and 41c. The aperture diameter is 1.673048. mm.

[0067] Row 4 of Table 5 shows that the radius of surface 41c is -22.14754 mm and the thickness of lens 104 is 0.5789873 mm.

[0068] Row 5 of Table5 shows that the radius of surface 41d 3.11468 mm and the distance between the vertex on surface 41d of lens 104 and surface 41e of lens 106 is 0.05402182 mm.

[0069] Row 6 of Table 5 shows that the radius of surface 41e is 3.603306 mm and the thickness of lens 106 is 1.100749 mm.

[0070] Row 7 of Table5 shows that the radius of surface 42c is -8.174966 mm and the distance between the vertex on surface 42c and the object surface 44 of lens 36 in Figure 1 is 0.7061964 mm.

Row 8 of Table 5 shows that the radius of surface 44 is -1.275432 mm. The thickness or dimension 68 of the middle lens element 36 between vertex 76 and 82 is 1.004195 mm.

[0071] Row 9 of Table 5 shows that the image surface 46 has a radius of -2.559828 mm. The thickness column provides the dimension 90 from the middle lens element vertex 82 to the final lens element object surface vertex 78. The dimension 90 is 0.485716 mm.

Row 10 of Table 5 shows that the radius of surface 48 is 9.962559 mm. The thickness or dimension 70 of the final lens element 38 between vertex 78 and 84 is 1.358772 mm

[0072] Row 11 of Table 5 shows that the image surface 50 has a radius of -40.95514 mm. The thickness column provides the dimension 92 distance from the final lens element vertex 84 to the center of the image plane 94 as being 0.984538 mm. The aperture diameter is 6.151768 mm.

[0073] Row 12 characterizes the image plane 26 as IMA, and with a radius that is infinity, the image plane is substantially flat.

Table 5						
SURFACE DATA SUMMARY (triplet 34c)						
Row	Surface Number	Type	Radius	Thickness	Index	Abbe
1	OBJ	STANDARD	Infinity	Infinity		
2	40c	STANDARD	2.25801	1.058656	1.803	46.7
3	41b	STANDARD	7.551701	0.1086743		
4	41c STOP	STANDARD	-22.14754	0.5789873	1.785	25.8
5	41d	STANDARD	3.114468	0.05402182		
6	41e	STANDARD	3.603306	1.100749	1.803	46.7
7	42c	STANDARD	-8.174966	0.7061964		
8	44	STANDARD	-1.275432	1.004195	1.847	23.8
9	46	STANDARD	-2.559828	0.0485716		
10	48	STANDARD	9.962559	1.358772	1.836	42.3
11	50	STANDARD	-40.95514	0.984538		
12	IMA	STANDARD	Infinity			

[0076] While certain specific relationships, materials and other parameters have been detailed in the above description of preferred embodiments, those can be varied, where suitable, with similar results. Other applications and variations of the present invention will occur to those skilled in the art upon reading the present disclosure. Those variations are also intended to be included within the scope of this invention as defined in the appended claims.